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(54) **METHOD AND APPARATUS FOR CASTING MOLTEN MATERIALS USING PHASE-CHANGE MATERIAL**

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(52) **U.S. Cl.** **264/3.1**; 86/20.12; 425/549; 425/551; 425/DIG. 245; 264/259
(58) **Field of Search** .... 264/3.1, 259; 86/1.1, 86/20.12; 425/86, 110, 549, 551, DIG. 245, 586

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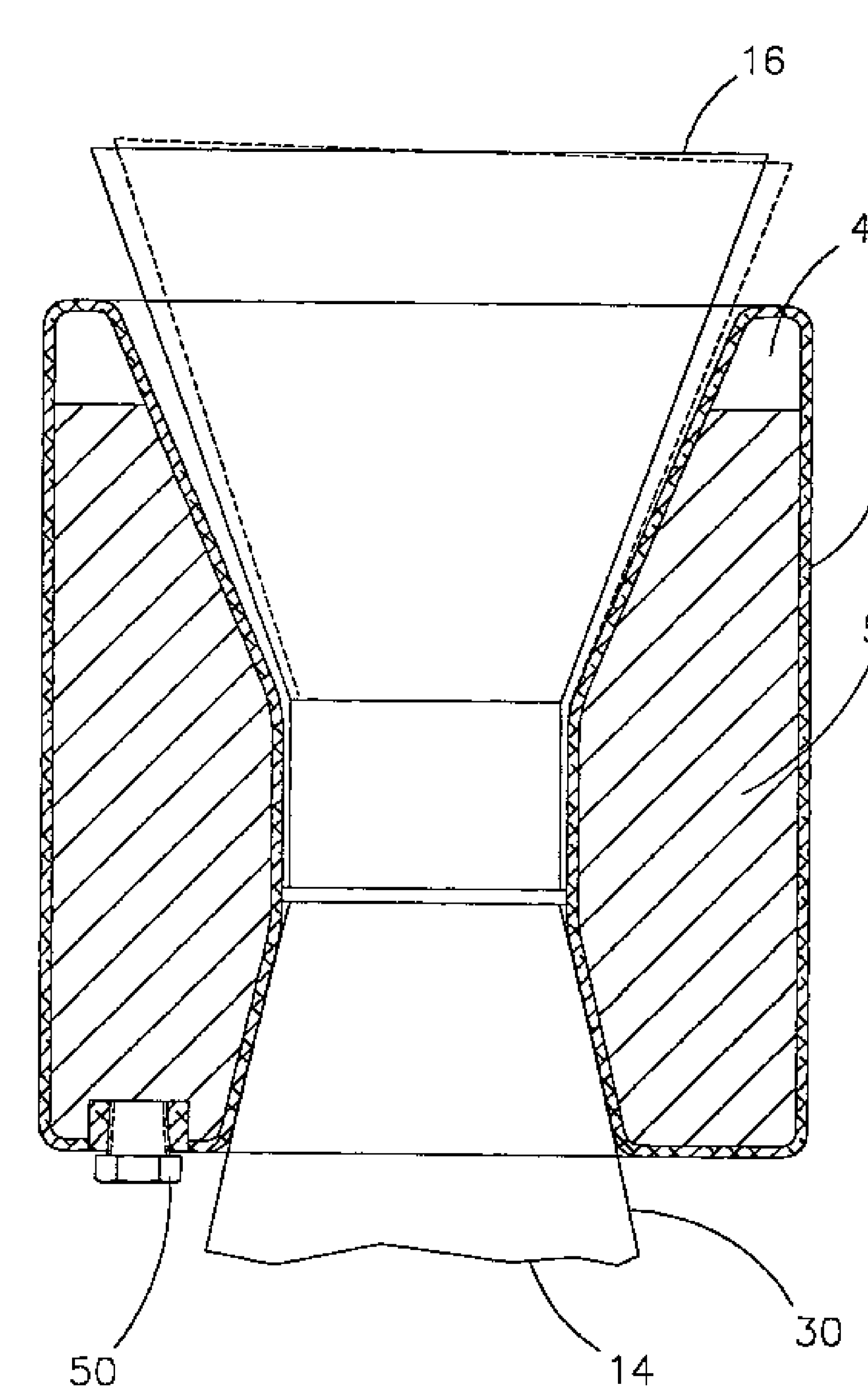
(57) **ABSTRACT**

A method and apparatus for casting a molten material using a phase-change material. A funnel means is provided that includes a reservoir containing a phase-change material. The funnel means is used in conjunction with a mold. The phase-change material is heated to a temperature above its melting point. A molten material is poured into the mold, and an excess amount of the molten material is retained in the funnel means after the mold is filled. The latent heat of fusion of the phase-change material provides heat to the funnel means as the phase-change material changes from a liquid to a solid. The heat from the phase-change material maintains the temperature of the molten material within the funnel above its melting point as the molten material within the mold begins to solidify and contract, thereby permitting the excess material within the funnel means to feed into the mold and fill any voids or porosities formed by the contraction of the material within the mold. The funnel means may also include a neck-engaging portion in thermal contact with the phase-change material for engaging an upper, or neck, portion of the mold to maintain molten material contained within that portion above its melting temperature for an extended period of time. The apparatus and method are particularly well suited for use in casting explosive projectile shells.

3 Claims, 8 Drawing Sheets



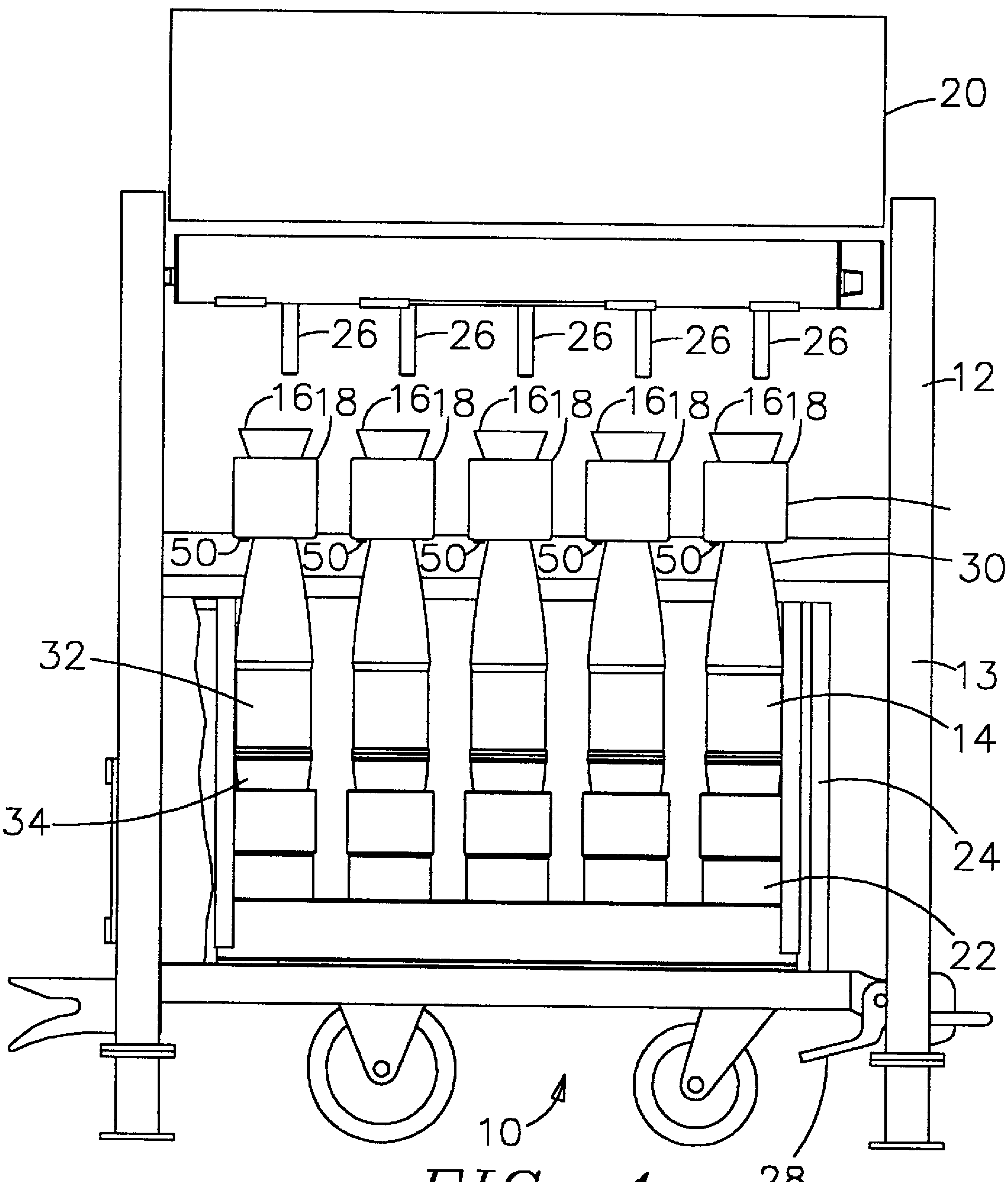

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FIG. 1

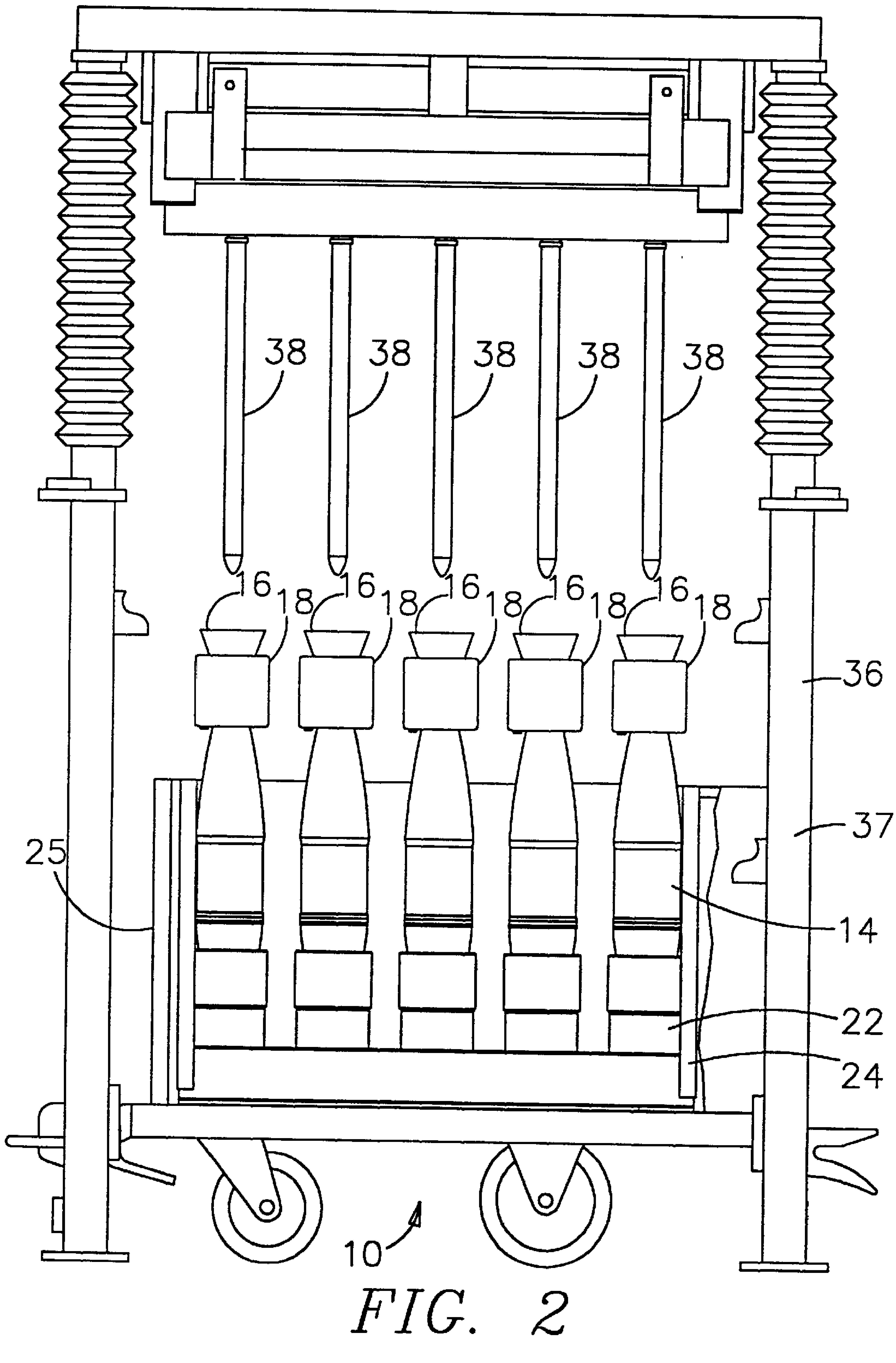

FIG. 2

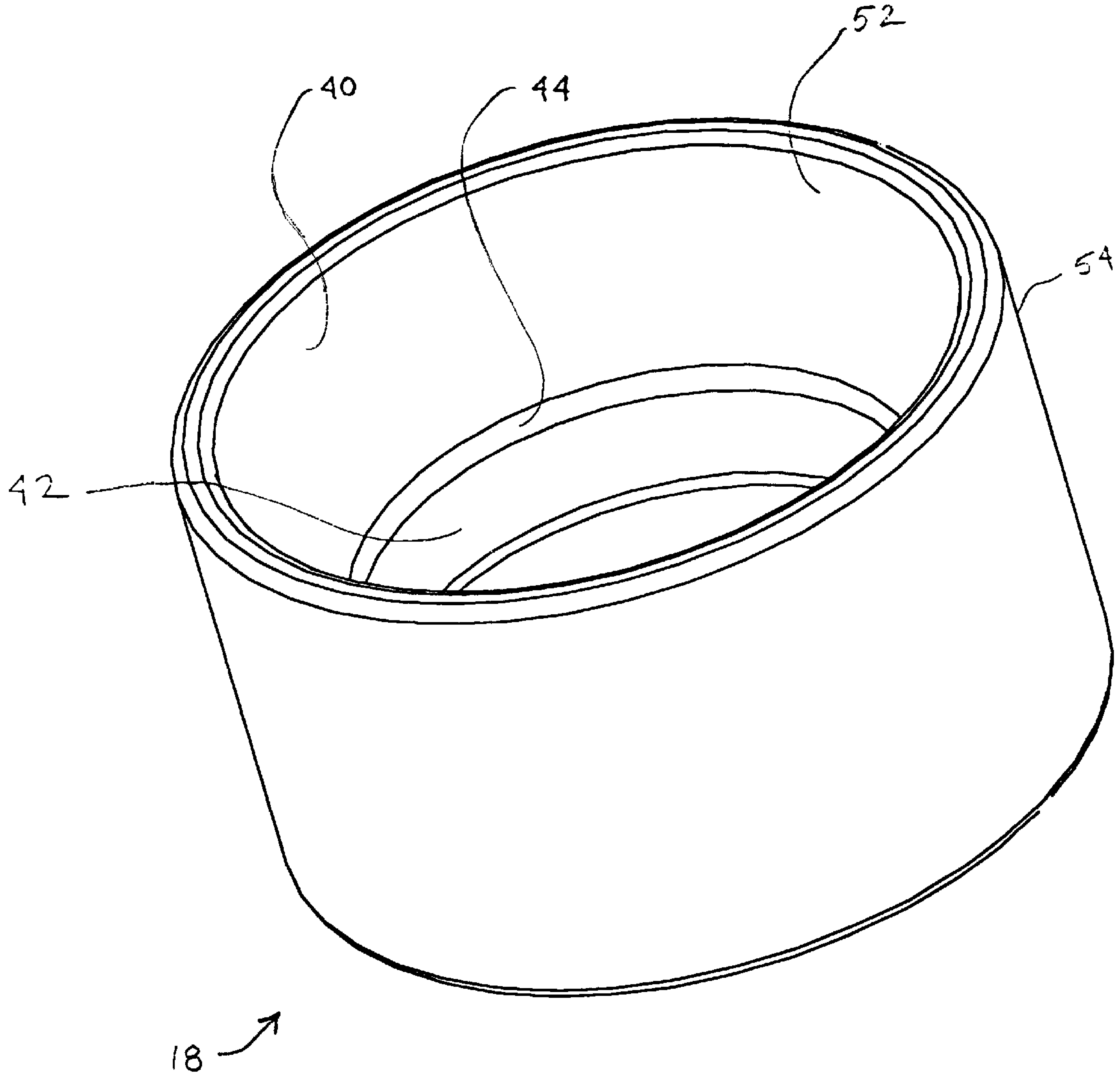

FIG. 3

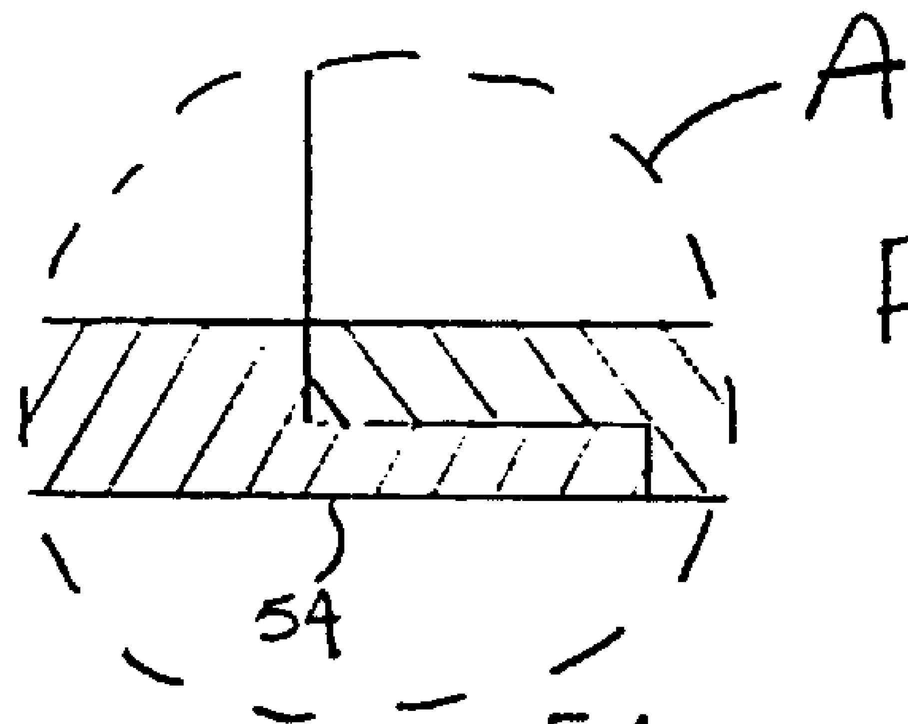

FIG. 4A

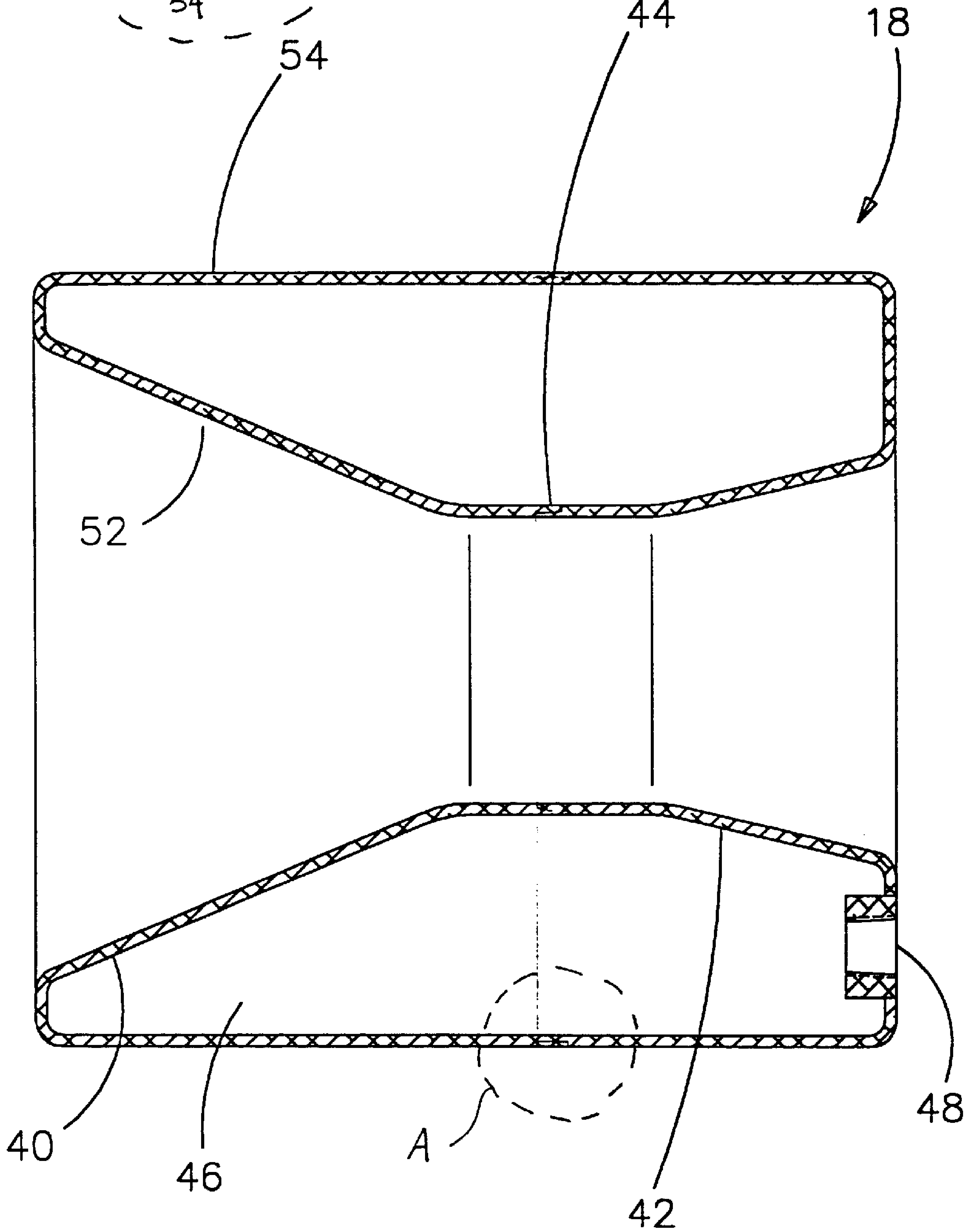

FIG. 4

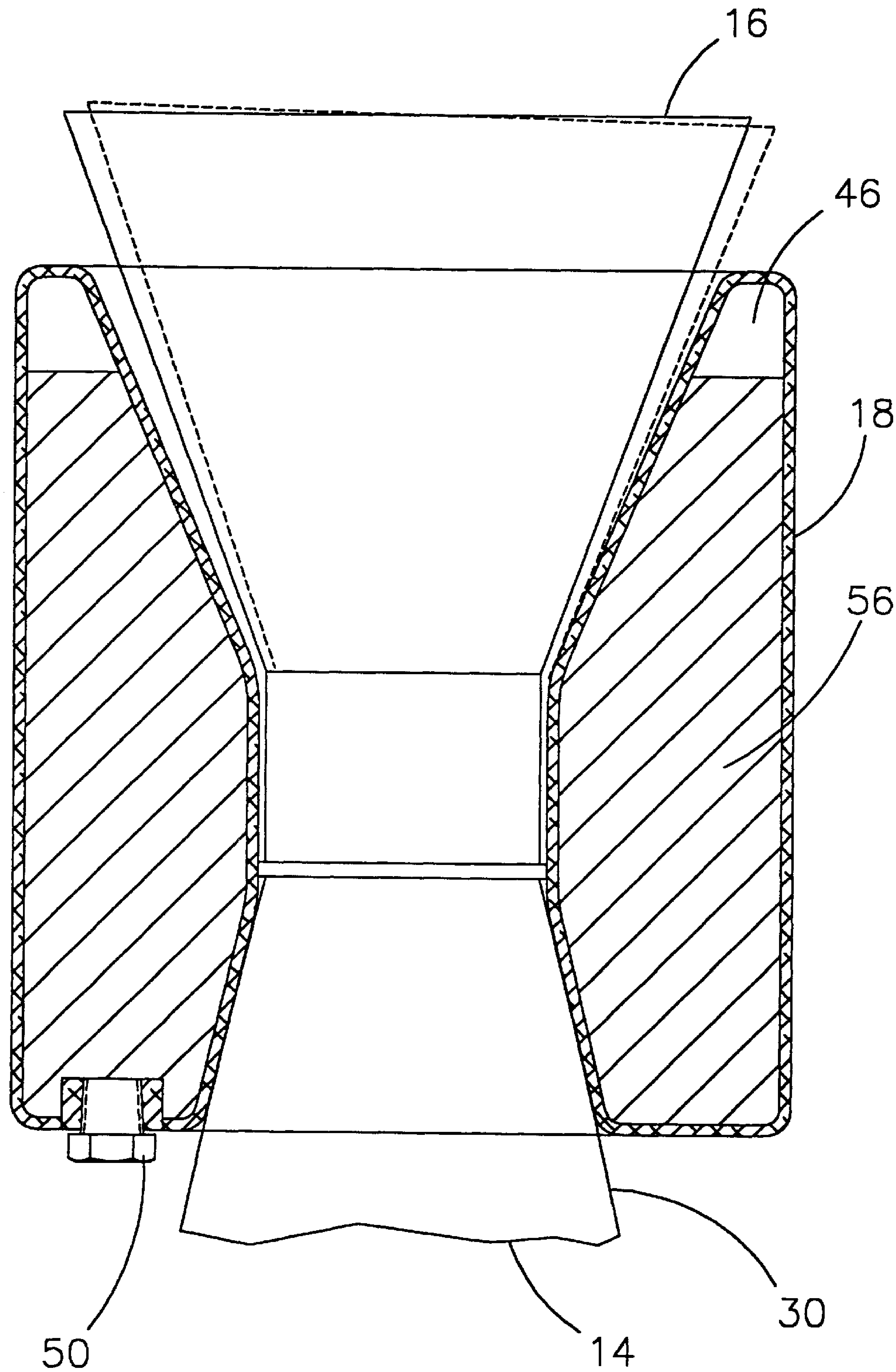

FIG. 5

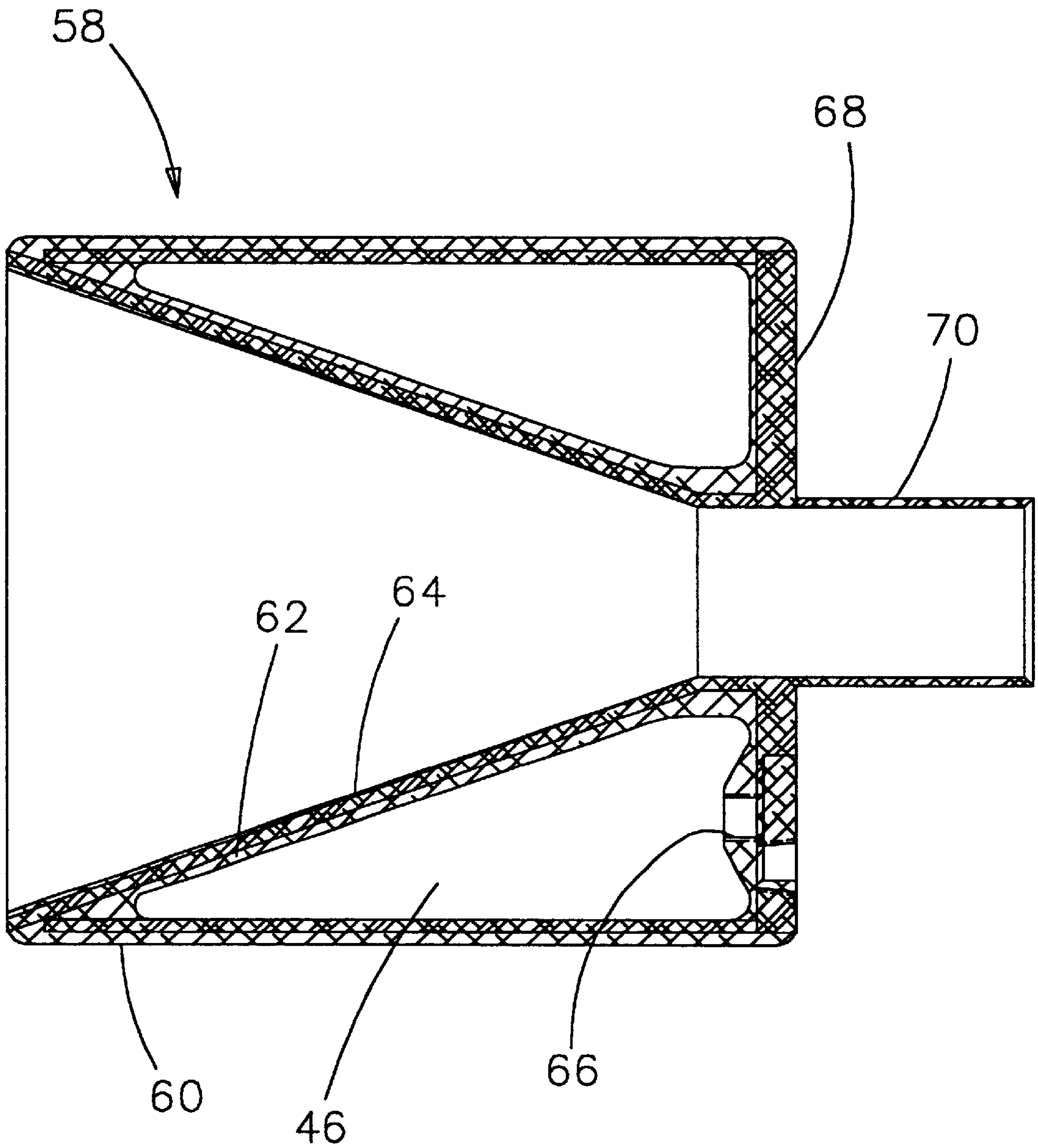

FIG. 6

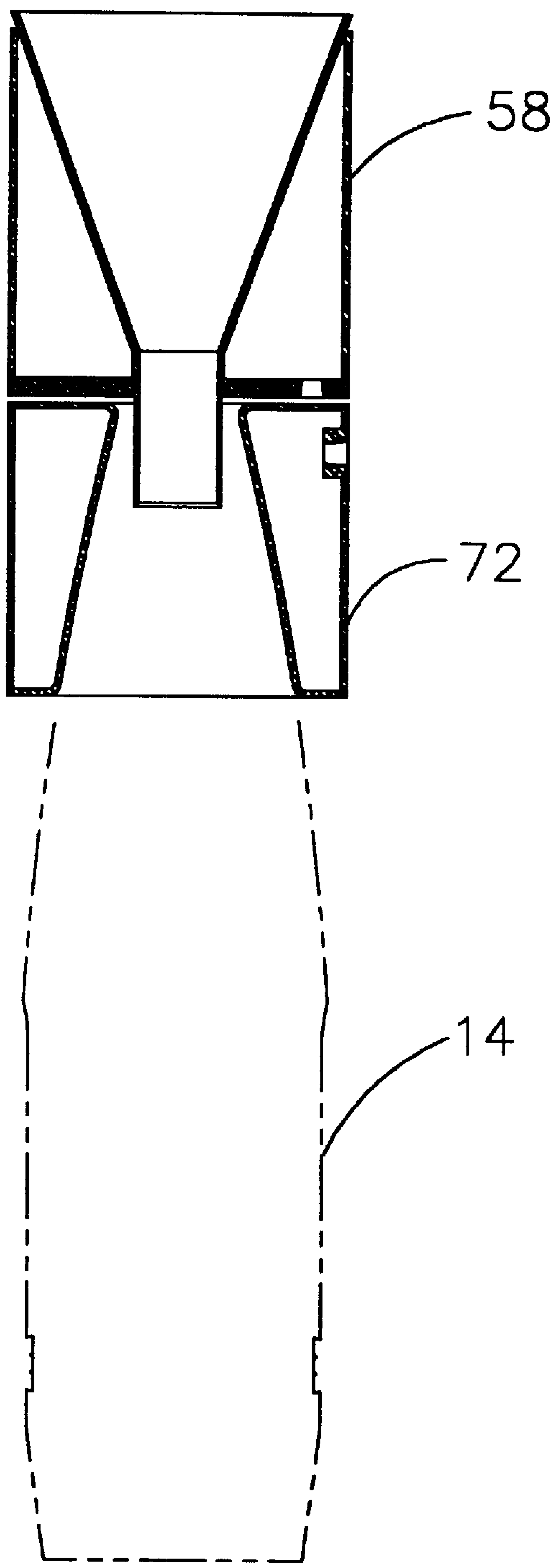

FIG. 7

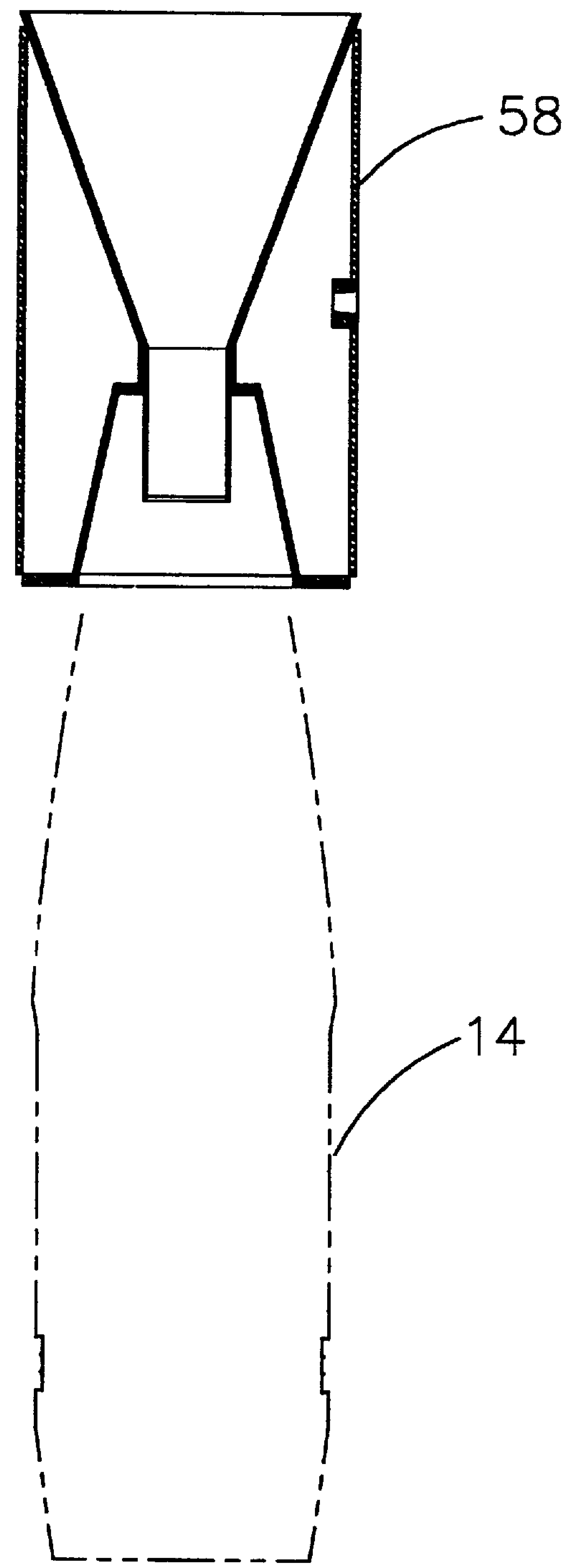

FIG. 8

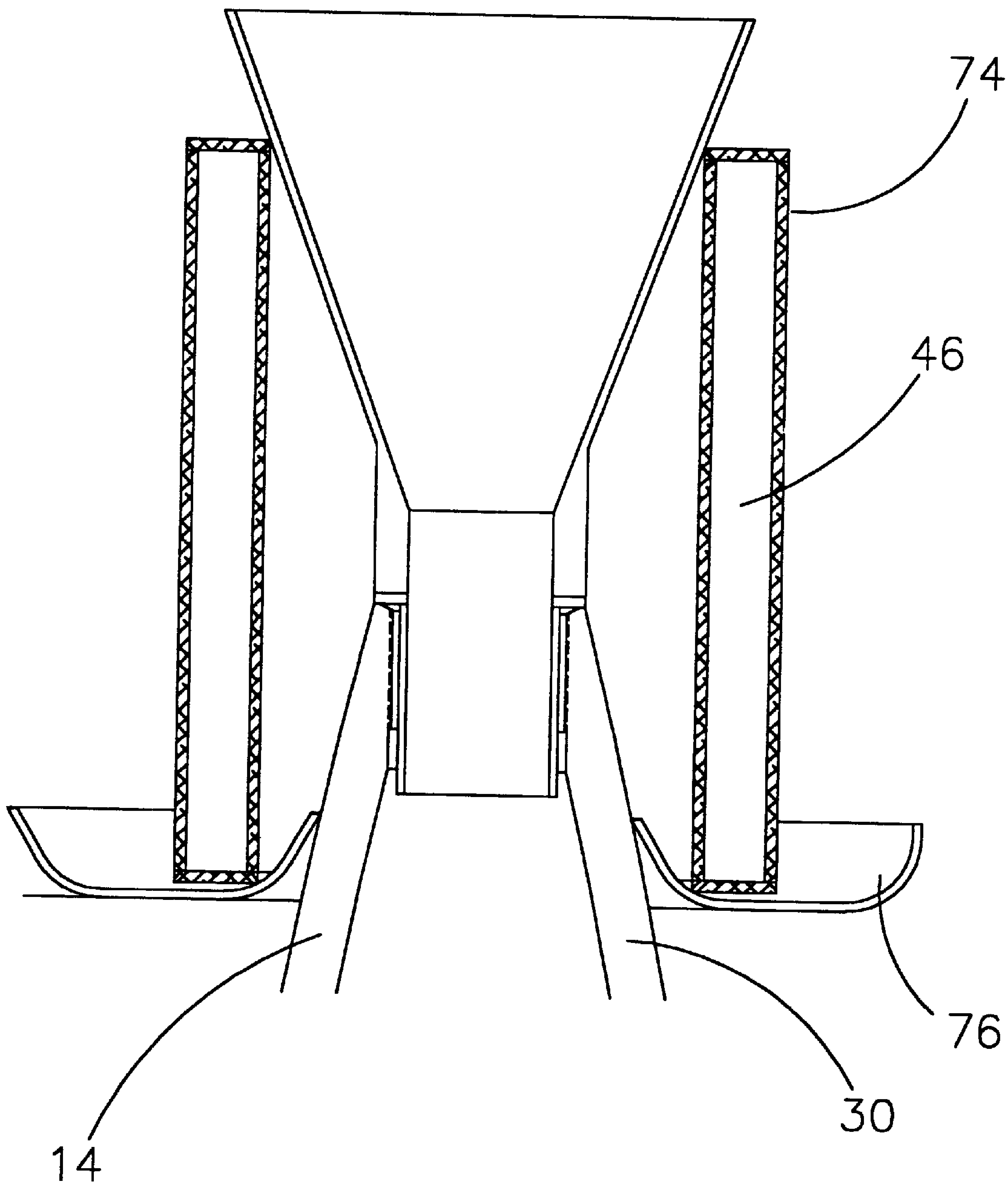

FIG. 9

METHOD AND APPARATUS FOR CASTING MOLTEN MATERIALS USING PHASE-CHANGE MATERIAL

TECHNICAL FIELD

The invention relates generally to method and apparatus used to cast molten materials. More specifically, the invention relates to a method and apparatus that includes a funnel insulated with a phase-change marerial used to cast explosives, especially explosive projectiles. The invention takes advantage of the latent heat of fusion of the phase-change material to maintain the funnel and projectile neck at an elevaled tempaerature during the casting and cooling process in order to keep the funnel and projectile neck open.

BACKGROUND OF THE INVENTION

A common method for manufacturing explosive projectilies involves pouring molten explosive material into a body casing. Typically, a funnel is used to help guide the molten explosive material into the projectile body. Explosives such as trnitrotoluenen (TNT) and composition B (a mixture of TNT and cyclotrimethylenetrinitramine (RDX) contract as they cool and harden into a solid. This contraction can cause gaps or porosities in the final product. These gaps are undesirable and can cause problems such as premature explosion in the gun barrel.

One strategy for avoiding the gaps is to overfill the projectile body during the initial pour of the molten explosive with the excess explosive being contained in the funnel immediately after the pour. If the explosive in the funnel is kept in a liquid state, it can feed into the projectile body, as the explosive in the projectile body hardens and contracts, thereby filling-in the gaps that otherwise form. In order to prevent the molten explosive from cooling too quickly and solidifying, it is known to insulate or heat the funnel.

If the funnel surface gets too cool, it can cause the molten material to harden and block the funnel. If the funnel surface gets too hot, that can cause problems as well. The high temperature heating surfaces present a safety hazard to users if the user skin would come in contact with the heated surface. Additionally, if the heated surface gets too hot, it can present a risk of explosion.

Funnels that are merely heavily insulated, but not provided with any source of heat, typically do not keep the funnel open for a sufficient time to prevent defects in the casting. Funnels that are provided with a heat source, such as hot water or steam oven panels typically will keep the funnel open for a sufficient period of time to allow for a complete casting. However, such methods of heating the funnels have a high initial cost and a high operating cost. If the temperature of the funnel surface is not carefully controlled, it may heat the molten explosive above the desired temperature. Another option is to preheat the funnel in an oven. The primary difficulty with this method is that the funnel must be prohibitively massive in order to retain enough heat to keep the funnel open for the required length of time. It can also be difficult to control, or even verify, the temperature of the funnel during the process when using this method. Additionally, because it is necessary to heat the funnel above the melt temperature of the explosive, this method can lead to heating the molten explosive above the desired temperature during the beginning of a pour.

An additional method of heating the funnels uses forced air. This also results in high costs because it requires the control of airflow to multiple ovens. It also requires proper ventilation to remove explosive fumes that may be carried in the heated air. Finally, the air temperature must be above the melting point of the explosive, and therefore tends to heat the molten explosive above desired temperatures.

Therefore, there exists a need for a method and apparatus that permits the casting of explosive projectiles that maintains the funnel open for a sufficient amount of time to permit a highly quality cast, but does not heat the molten explosive above desired limits. Preferably, the apparatus will not have a high initial cost or a high operation cost, will be safe to use, and will be consistent and reliable.

The present invention satisfies the above identified needs.

SUMMARY OF THE INVENTION

The present invention is directed to an insulator and funnel for use in pouring explosive projectiles. The funnel has a sloping funnel surface in thermal contact with a reservoir in the insulator. The reservoir contains a phase-change material. The phase-change material has a melting point that is higher than the melting point of the explosive material. Preferably the phase-change material is also in thermal contact with a top, or neck portion of the projectile body. The phase-change material is preheated to a temperature sufficient to melt the phase-change material. A molten explosive material is poured through the funnel into a projectile body. As the phase-change material changes from a liquid to a solid, the latent heat of fusion of the phase-change material maintains the sloping surface of the funnel and projectile neck at a near constant temperature that is warm enough to permit the molten explosive material to flow through the funnel and projectile neck for a sufficient amount of time to supply molten explosive into the projectile body as it cools, shrinks, and solidifies.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial cut-away front view of a cart used to cast explosive projectiles with phase-change funnels in place on the projectile bodies.

FIG. **2** is a cut-away front view of the cart and bodies from FIG. **1** in place under a heated probe machine.

FIG. **3** is a perspective view of a funnel insulator according to the present invention.

FIG. **4** is a sectional view of the funnel insulator of FIG. **3**.

FIG. **4A** is a detail close-up view showing the seam of the two halves of the preferred embodiment of the funnel insulator of FIG. **4**.

FIG. **5** is partial assembly view showing the insulator of FIG. **3** in place on a projectile body with a funnel resting in the funnel insulator.

FIG. **6** is a sectional view of an alternative embodiment of an insulated funnel.

FIG. **7** is a sectional view of an assembly for insulating a funnel and the neck of a projectile body during a casting process.

FIG. **8** is a sectional view of alternative embodiment utilizing a single element for insulating a funnel and a neck of a projectile body.

FIG. **9** is an assembly view of an alternative embodiment of a right rectangular phase-change insulator sleeve.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Shown generally in FIG. **1** is an arrangement used to manufacture explosive projectile bodies according to the present invention. More specifically, FIG. **1** shows a cart **10** in operational position beneath a loading machine **12**. The loading machine **12** includes a pair of uprights **13** that support a manifold **20** which contains molten explosive material. Included on the cart **10** is a rack **22**, which holds projectile bodies **14** in an upright position. Each projectile body **14** can be divided into three general sections: A neck **30** at the top of the body, a body **32** in the middle, and a base **34** at the bottom. The bases **34** of the projectile bodies **14** are placed within the rack **22**. Funnel insulators **18** rest on the necks **30** of the projectile bodies **14**, and extend above the top of the necks **30**. Funnels **16** are fitted within the funnel insulators **18**, and extend downwardly into the neck **30** of the projectile bodies **14**. The loading machine **12** has pouring spouts **26** aligned above corresponding funnels **16**. The spouts **26** are in flowable connection with the manifold **20** such that molten explosive material can flow from the manifold **20** through the spouts **26** and into the funnels **16**. A latch **28** is provided on the cart **10** to allow multiple carts to be locked together. The cart **10** shown in FIGS. **1** and **2** includes walls **24** that form a tank **25** that can be used to hold cooling water; however, in the preferred embodiment air is used to cool the projectile bodies **14**, and the tank **25** is not included on the cart **10**.

FIG. **2** shows the cart **10** in a working position beneath a probe machine **36**. The probe machine **36** includes uprights **37** that support probes **38**. The probes **38** can be selectively heated to a temperature hot enough to melt common explosives that might be used in projectile bodies. The cart **10** is placed in the probe machine **36** such that each of the probes **38** is in alignment with a corresponding funnel **16**. The probe machine **36** is adapted such that the probes **38** can be selectively lowered into the funnels **16** and into the necks **30** of the upright projectile bodies **14**.

The details of the pre erred funnel insulator **18** are best seen in FIGS. **3** and **4**. The funnel insulator **18** is a toroid having a generally planar outer wall **54** in the form of a right rectangular cylinder and a segmented inner wall **52**. The inner wall **52** comprises a sloping funnel supporting section **40**, a tap red neck engaging section **42**, and an intermediate section of **44** that is generally a right rectangular cylinder. The funnel insulator **18** is hollow such that its interior forms a reservoir **46**. An orifice **48** is provided through the walls of the funnel insulator **18** such that a phase-change material **56** may be introduced into the reservoir **46**. A copy **50** is provided to plug the orifice **48**. The funnel insulator **18** can be formed from a variety of materials such as plastic or aluminum. Whatever material is chosen must have a melting point higher than that of the explosive and phase-change material **56** being used.

FIG. **5** shows a sectional view of a funnel insulator **18** in place on the neck **30** of a projectile body **14**. A funnel **16** extends through the funnel insulator **18** into the neck portion **30** of the body **14**. The wider mouth portion of the funnel **16** extends above the top of the funnel insulator **18**, and the narrow output portion of the funnel **16** extends into the neck **30** of the body **14**. The funnel insulator **18** is designed such that its inner wall **52** slopes at a slightly shallower angle then the sides of the funnel **16**. This difference in the slopes allows some "play" between the funnel **16** the funnel insulator **18**, which can be important when removing the funnel **16** from the hardened projectile.

FIG. **6** shows an insulated funnel **58**. The insulated funnel **58** is an alternative to the combination of a funnel insulator **18** and funnel **16**. The insulated funnel **58** is a toroid comprising basically an outer wall **60**, and inner wall **62**, and a bottom wall **68**. The walls **60**, **62**, and **70** enclose a reservoir **46**. An orifice **66** is provided through the bottom wall **68** so that a phase-change material **56** may be introduced into the reservoir **46**. A lip **70** extends below the bottom wall **68** around the inner radius of the toroid. As seen in FIG. **7**, when in use, the bottom wall **68** of the insulated funnel **58** sets on the top of a projectile body **14**, and the lip **70** extends into the neck portion **30** of the projectile body **14**. The primary advantage of the insulated funnel **58** is that it does not require a separate funnel. The disadvantages of using an insulated funnel **58**, as opposed to a combination of a funnel **16** and a funnel insulator **18**, are that the surfaces that come in contact with the explosive may be difficult to get completely clean of explosive material. If even a small residue of explosive remains on the insulated funnel **18** during the heating process, it can be dangerous. Furthermore, it can be difficult to construct the insulated funnel **58** so that it can withstand the "knocking" process of removing the insulated funnel from the hardened explosive after the projectiles have cooled.

The insulated funnel **58** may be used in conjunction with a separate neck insulator **72**, as seen in FIG. **7**, or the insulated funnel may be formed as shown in FIG. **8** such that it includes a portion that extends over the neck portion **30** of the projectile body **14**. The advantage to the configuration shown in FIG. **7** including separate insulated funnel **58** and neck insulator **72** is that different phase-change materials **56** may be used within the two reservoirs formed in the insulated funnel **58** and the neck insulator **72**. It may be desirable to use a phase-change material with a higher melting point in the funnel **16** so that it remains open and flowable even after the neck portion **30** begins to solidify.

FIG. **9** shows an insulating sleeve **74** that can be placed around the neck **30** of a projectile body **14** and funnel **16** during the loading process. A splash pan **76** is integrated with this design to catch any splashes or spillages of the molten explosive as it being poured into the projectile body **14**. The insulating sleeve **74** is formed to include a reservoir **46** for holding a phase-change material **56**. The insulating sleeve **74** has the advantage of being relatively easier to manufacture than the insulated funnel **58** or funnel insulator **18**, but does not make thermal contact with the funnel surface as efficiently. The splash pan **76** can also be used with the other funnel insulators **18** or insulated funnel **58**, to catch any explosive spilled in the loading process.

The preferred phase-change material **56** is wax. Wax of varying melting points may be used depending on what molten material is being cast, and the heat transferred characteristics of the funnel insulator **18** and funnel **16**. TNT has a melting temperature of approximately 177.5° Fahrenheit. For TNT, a wax with a melting point of between 208° Fahrenheit and 232° Fahrenheit has been found to be effective. Another common explosive is composition B. Because composition B is poured into projectiles with a high solids content, i.e., sixty percent of RDX in composition B is not molten, it may be desirable to use a phase-change material that has a higher melting point. Those of ordinary skill in the art may be aware of other phase-change materials that will be acceptable. The important criteria for the phase-change material **56** are that its melting point is high enough so that as it changes from a liquid into a solid it will provide enough heat to the funnel **16** and neck **30** for a sufficient time to prevent premature solidifying of the molten explosive in the funnel **16** and neck **30** during the casting process, and that the melting temperature be low enough that the phase-change material **56** does not raise the temperature of the funnel **16** too high.

Thus far the structure and equipment needed to cast explosive projectiles according to the present invention has been discussed. The process for casting such projectiles will now be discussed. The first step is to load the empty projectile bodies **14** onto the rack **22** on the cart **10** in an upright orientation. The bases **34** of the projectile bodies **14** are placed in the rack **22** such that an opening in the neck **30** of each of the projectile bodies **14** is exposed at the top of the projectile body **14**. The cart **10** with the loaded projectile bodies **14** is then moved into an oven to preheat the projectile bodies **14** before the casting process. Typically, the projectile bodies **14** are heated to a temperature between 100° Fahrenheit and 165° Fahrenheit. The funnel insulators **18** are also placed into an oven and preheated to a temperature above the melting point of the phase-change material **56**. Once the funnel insulators **18** have been heated sufficiently to melt all of the phase-change material **56** within the reservoirs **46**, the funnel insulators **18** are removed from the oven and assembled in place on the projectile bodies **14**, as best seen in FIG. **1** along with the funnels **16**. When assembled in the loading position, the neck engaging section **42** of the funnel insulator **18** rests on the neck **30** of the corresponding projectile body **14**. The funnel **16** is then placed inside the funnel insulator **18** such that the sides of the funnel **16** are in contact with the funnel supporting section **40** of the funnel insulator **18**. The funnels **16** include a lip that extends from the bottom of the funnel **16** into the opening at the top of the preheated projectile body **14**.

The cart **10** loaded with the preheated projectile bodies **14** is then moved into working position under loading machine **12**. With the cart **10** in a proper loading position, the funnels **16** are each in alignment with a corresponding spout **26**. Optionally, the cart **10** may have a series of loading positions wherein each row of projectile bodies **14** and funnels **16** are placed in alignment with a row of spouts **26**. Molten explosive from the manifold **20** can then be poured through spouts **26** into corresponding funnels **16**, which funnel the molten explosive into the projectile bodies **14**. The projectile bodies **14** are overfilled so that a reserve of molten explosive is contained in the funnels **16**. This reserve explosive is necessary to fill the projectile bodies **14** as the explosive solidifies and contracts. Typically TNT will shrink about 13% as it cools and solidifies. The process can be carried out in an environment having a room temperature of between 85° to 125° Fahrenheit. The surface of the funnel **16** is cooled by the air in which it comes in contact with. However, due to the latent heat of fusion, the phase-change material **56** provides a source of heat **56** to the funnel **16** at a constant temperature equal to the melting temperature of the phase-change material. This keeps the surface of the funnel **16** and the neck **30** of the projectile body **14** heated above the melting point of the explosive for a sufficient amount of time, which permits the explosive material in the funnel **16** to flow into the projectile body **14** as the explosive material in the projectile body solidifies and shrinks.

The filled projectile bodies **14** and the funnels **16** and funnel insulators **18** may then be covered with a canvas shroud to further insulate the funnels **16** and projectile neck **30** and to prevent foreign bodies or contaminants from falling into the funnel **16**. The cart **10** with the covered projectiles **14** can then be moved to a cooling area. The projectiles **14** are allowed to cool in ambient air for approximately 2–8 hours. Alternatively, a tank may be incorporated with the cart **10** surrounding the projectile bodies **14**, filled with water to speed the cooling process. Once the explosive within the funnel **16** solidifies sufficiently to block the opening in the funnel **16** (a process known as "necking off"), the cart **10** is moved into position under the probe machine **36**, as seen in FIG. **2**. The shroud is removed, and the heated probes **38** are lowered into the neck **30** of the projectiles **14**. Preferably the probes are heated to a temperature somewhat above 220° Fahrenheit to melt open the neck area **30** of the projectiles **14**. An additional amount of explosive necessary to completely fill the projectile body **14** is then poured into the open funnel **16**. The projectiles **14**, the funnel insulators **18**, and the funnels **16** are then re-covered by a canvas shroud and the cart **10** with the covered projectiles are moved to a cooling area and the projectiles **14** are allowed to cool for an additional 2–5 hours.

The funnels **16** are manually broken away from the projectiles **14**, and the funnels **16** and funnel insulators **18** are removed from the projectiles **14**. The play between the funnels **16** and the funnel insulators **18** aids the process of breaking the funnels **16** away from the projectiles **14**. The threads on the opening of the projectiles **14** are cleaned to remove to any excess explosive material. The projectiles **14** may then be radiographically inspected to check for any defects. The funnels **16** and funnel insulators **18** can then be washed and reused.

The foregoing description of preferred embodiments is meant to be illustrative of the invention, and the invention should not be considered as being limited to the embodiments described herein, except as limited by the following claims. For example, while the process is described in connection with the creation of explosive projectiles, the invention should application to the casting of other products.

What is clawed is:

1. A method of forming a cast article from a casting material that contracts as it solidifies, the method comprising:

providing a mold with an opening:

providing a supply of molten casting material;

placing a funnel in working engagement with said opening in said mold, said funnel having an inner funnel surface for guiding said molten casting material into said mold;

providing a funnel insulator having a reservoir in thermal contact with said inner funnel surface;

wherein said funnel and said funnel insulator are separable pieces, wherein said funnel insulator includes a funnel-shaped surface in thermal contact with said reservoir, said funnel-shaped surface tapering from a relatively wide upper opening at a relatively narrow lower opening, wherein said funnel includes an outer funnel surface that has a slope that is steeper than a slope of said funnel-shaped surface of said funnel insulator such that there is some play between said funnel and said funnel insulator when said funnel is placed in nested engagement with said funnel-shaped surface of said funnel insulator such that said funnel can rock laterally within said funnel-shaped surface;

placing said funnel in nested engagement with said funnel-shaped surface of said funnel insulator prior to pouring said molten material into said mold;

providing a portion of phase-change material within said reservoir;

heating said portion of phase-change material to at least partially melt said portion of phase-change material;

pouring said molten casting material into said mold until said mold is completely filled and an excess amount of molten casting material is retained within said funnel;

allowing said molten casting material within said mold to cool as said phase-change material provides heat to said inner funnel surface while said heated portion of phase-change material at least partially changes from a liquid phase to a solid phase, said heat from said phase change material maintaining said excess amount of molten casting material in said funnel above a melting temperature such that said excess amount of molten casting material within said funnel can feed into said mold as said casting material in said mold solidifies and contracts;

allowing said casting material within said mold to cool and harden into a cast article; and

removing said funnel from aid funnel insulator by breaking said funnel away from said cast article after allowing said explosive material within said projectile shell to cool and harden, said play between said funnel and said funnel-shaped surface aiding the process of breaking said funnel away from said cast article.

2. A method of creating explosive projectiles comprising:

providing a projectile shell said projectile shell including an opening at a neck portion of said projectile shell;

providing a portion of explosive material, said explosive material being of the type that contracts as it changes from a molten form to a solid form;

placing said projectile shell on a wheeled cart with said opening facing generally upwardly;

providing a funnel insulator said funnel insulator including a reservoir, said reservoir being at least partially filled with a phase-change material, said funnel insulator further including a generally funnel-shaped surface in thermal contact with said reservoir, said funnel-shaped surface tapering from a relatively wide upper opening at a relatively narrow lower opening;

heating said phase-change material to at least partially melt said phase-change material;

placing said funnel insulator on said neck portion of said projectile shell such that said lower opening in said funnel insulator is in communication with said opening in said projectile shell;

providing a funnel, said funnel having an inner funnel surface for guiding said explosive material into said projectile shell and an outer funnel surface, said outer funnel surface having a slope that is steeper than a slope of said funnel-shaped surface of said funnel insulator said difference in said slopes allowing some play between said funnel and said funnel-shaped surface when said funnel is nested in said funnel-shaped surface such that said funnel can rock laterally within said funnel-shaped surface;

placing said funnel in nested engagement with said funnel-shaped surface of said funnel insulator;

moving said wheeled cart into a loading position such that said inner funnel surface of said funnel is beneath and in alignment with a loading spout;

melting a portion of said explosive material to create a portion of molten explosive material;

pouring said molten explosive material out of said loading spout and across said inner funnel surface into said projectile shell to fill said projectile shell and at least partially fill said funnel;

allowing said molten explosive material to cool within said projectile shell while said heated phase-change material at least partially changes from a liquid phase to a solid phase, said phase-change material providing heat to said inner funnel surface to maintain said molten explosive material within said funnel above a melting temperature of said explosive material and thereby permit said molten explosive material in said funnel to feed into said projectile shell as said molten explosive within said projectile shell solidifies and contracts;

allowing said explosive material within said projectile shell to cool and harden to form an explosive projectile comprising said hardened cooled explosive material and said projectile shell; and

removing said funnel from said funnel insulator, said removal of said funnel insulator being aided by said play between said funnel and said funnel insulator.

3. The method according to claim **2**, wherein said funnel insulator further comprises a neck engaging portion in thermal contact with said phase-change material reservoir, said neck engaging portion being adapted to engage said neck portion of said projectile shell to maintain said molten explosive within said neck portion of said projectile shell above said melting temperature of said explosive material as said explosive material in other portions of said projectile shell solidifies and contracts.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,635,197 B2 Page 1 of 1
APPLICATION NO. : 09/891117
DATED : October 21, 2003
INVENTOR(S) : John David Cortum, Michael Jaye Mathiasmeier and Louis William Stoecker

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On title page item [73] should read,
Assignee is American Ordnance LLC, Middletown, IA (US)

Signed and Sealed this

Third Day of February, 2009

John Doll

JOHN DOLL
Acting Director of the United States Patent and Trademark Office